Precipitation Enhancement in China£¬A Developing Technology for Obtaining Additional Water from Sky

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Abstract: General information about the precipitation enhancement activities in China is given, including its social demand, organization and scale scientific foundation, technology of cloud seeding and effect evaluation. Future development is also discussed.

1. Water scarcity and drought damage in the North of China

1.1 Water scarcity

In the North of China the annual average rainfall is 544mm, total amount of water resources is 128mm, which is about 65 % and 40 % of the world mean value over land. There are many provinces that have renewable fresh water far under 1000 m^3 per capita per year, commonly accepted as a benchmark for water scarcity.

1.2 Large variation of precipitation

Precipitation in the North of China has very large variation both in space and time, due to the impact of monsoon climate. The average annual rainfall decreases from southeast to northwest, from 1000mm to 100mm. Annual relative variation of rainfall is about 30%; ratio of the maximum value to the minimum one is 2-5 (for 30-years period). The most part (50%-70%) of the annual rainfall occur in summer, and only 15% occur in spring. Rainfall in rainy season is usually concentrated in a few cases of torrential rain.

1.3 Frequent occurrence of drought

According to the statistics for 30 years (1951~80) droughts in middle to large scale occurred in 28 years (93%), severe drought damage appeared 11 years (37%). Drought occurred frequently in spring season (80%). Spring drought in large scale occurred for 13 years (43%).

1.4 Intensification scarcity in recent 20 years

In large part of the North of China the annual rainfall decreased significantly in recent 20 years. The growth of population and the development of economy lead to a high increase of water demand. Water shortage, frequent droughts, fall in ground water level, break of streamflow in Huanghe River and other water problems attract great attention from government and society.

2. Status of precipitation enhancement activities in China.

2.1. Scale of activities

Precipitation enhancement (PE) started in 1958 in China. In recent years PE activities have drawn greater attention and support from government at different levels and has been highly commended by the people who have benefited from it. In 1997, 18 provinces mainly in the North of China conducted PE operations by using 360 flights of airplane. 1167 counties (about 40% of the total) were involved in artillery shooting and rocket launching activities for PE and hail suppression.

2.2. Organization and management

At present PE activities in China are mainly organized and financially supported by local government at different levels. They are managed, conducted, and guided in technology by local meteorological administration. At national level, "National Coordination meeting on Weather Modification" has been created in 1994, which is responsible to organizing, coor-dination and guiding the weather modification activities across the country. 13ministries and committee take part in this meeting, the permanent office of which is located at China Meteorological Administration.

2.3. Purpose of PE activities.

The PE activities in China are mainly aimed at mitigation of the drought damage. In the North of China drought occurs almost every year and covers a large area, so the PE activi-ties in many provinces are carried out regularly in spring seasons. In the South of China droughts usually occur in a seasonal and local manner, the PE activities are usually carried out urgently.

In recent years more attention is paid to PE for obtaining additional water in the catchment area of reservoirs or river. This kind of PE activities will be carried out regularly in the wet season, when the cloud condition is much better than that in the drought situation. A PE project in the upper reaches of Huanghe River may be a recent example.

PE operation was also used for prevention of the forest fire and protection of the crops from severe cold through the increase of snow cover in winter.

3. Physical foundation

3.1. Structure and PE potential of stratiform cloud

In the north of China precipitation in spring is produced mainly by stratiform cloud system of synoptic scale. Observations of airborne PMS and impactor, combined with the radar, satellite, microwave radiometer and dense rawinsonde etc. showed that:

(1)❄The concentration of cloud droplets and CCN is relative large and belongs to the continental type;

(2)❄Concentration of ice(and IN) is large , which reaches 10~70/L;

(3)❄Suppercooled water content is small, ranging from 0.02~0.25 g/m^3, which decreases significantly with the decrease of temperature and disappears below -20°Ê It was also shown that the precipitation structures agreed with the "seeder-feeder" concept and the upper seeder cloud sometimes had the shape of bands with width of 20-40km. PE potentials for ice seeding existed in such places where the upper seeder cloud was not strong enough and the supercooled water still existed in the lower feeder clouds. There were better PE potentials in region of orographic lifting or convection.

3.2. Structure and PE potential of convective clouds.

Convective clouds usually developed in summer season. Observations of airplane, radar, time-lapse photograph etc. showed that:

(1)❄The cloud was continental according to its large concentration of cloud droplets.

(2)❄Cloud base temperature was high, water content was great.

(3)❄Large droplets were numerous.

(4)❄Vigorous Cu cong cloud with top height of 6-8km might produce rain, but its contribution to the total rainfall was much smaller than that from the Cb cloud.

(5)❄Observed crystallization of cloud top corresponded to the temperature of -16°-27°Ê

Warm cloud seeding was emphasized in 1960's, introduction of large amount of salt particles in Cu cong clouds leaded to some rain-enhancement effects, but there were diffi-culties in dealing with the large amount of corrosive material. On account of the most con-tribution of Cb clouds to the total rainfall and the high efficiency of the ice forming technology, introduction of ice-forming agent in developing Cb cloud (mainly by artillery shoot) was adopted for rain enhancement through its microphysical and dynamical effects.

3.3. Numerical studies on PE.

One two, three dimensional numerical models of stratiform cloud and convective cloud have been created since 1970's to predict the water contents and number concentrations of various hydrometeors in cloud. Calculated results agreed with observations in many aspec-ts for numerous cases.

Numerical experiment on PE in stratiform clouds with adding artificial ice locally in concentration of 10^5 / m^3 showed significant increase of rainfall for about 2 hours. Small decrease was shown before and after this period, and the total rainfall was increased for about 20%. Analysis showed that the increased rainfall came from not only the supercooled water but also the vapor through the intensified sublimation. Three dimensional model showed significant dynamical effect of seeding, local temperature increased for several tenths degree and updraft increased for more than 10cm/s, which was favorable for cloud growth.

Numerical experiment on PE in convective clouds showed that the salt-seeding gave rise to a lower and earlier initial radar echo and the increase of rainfall.

It was also showed that the radar echo in warm base convective clouds initiated in warm region. Introduction of artificial ice with concentration of 10^5 /m^3 when the echo rose to the cold region might lead to prolonged, widen and increased rainfall. Ice seeding in developing stage of cold-base convective clouds with top height of 6-9km gave rise to the significant increase of rainfall.

4. Technology of PE operation

4.1. Seeding technology

(1) Dry ice, liquid nitrogen and AgI were used in airplane for seeding in stratiform clouds. The improved AgI-acetone burner could produce ice faster and more (from 10^{13} to 10^{14} ice per gram AgI at -10°C). Artillery shells containing AgI were used widely, the nucl-eation rate of which was increased in recent years from 10^9~10^{10}/g to 10^{12} /g AgI. AgI pyrotechnics were developed for airborne flares and rockets, nucleation rate of which reached 10^{14} -10^{15}/g, according to the tests in 2 m^3 isothermal cloud chamber.

(2) Particles of common salt, calcium chloride, urea were used in airplane for warm cloud seeding. The seeding dosage was much greater than ice forming agents.

(3) The maximum heights of delivery by using various carriers in China were as following: airplane~7km, artillery of 37mm caliber ~6km, various types of rockets ~4-8km.

4.2. Operation command system

The computer –communication system for operation command was established in many provinces in 1990's in purpose of real time data collection and procession and the PE dec-ision making and command. Its functions were:

(1) Collecting and displaying the meteorological data of various types, forecasting and monitoring the weather and cloud conditions for PE;

(2) Establishing the software system of judging the suitability of PE operation and deciding the place, time and dosage of seeding;

(3) Collecting data of rainfall and other observed properties of cloud, seeding parameters, airplane track etc. for evaluation of the PE effects;

(4) Coordinating with the airtraffic control organization, communication with all operation points, airplanes and observation points for accomplishment of the PE operations.

4.3. Effect evaluation

Evaluation of the PE effect is a very difficult problem, especially for the operations aimed at deducing drought disasters, users of which cannot accept the randomized design.

(1) The airplane PE operation in the North of China usually covered a large extent, the target regions were hardly fixed, and therefore the floating target-control areas or multi-target-control areas had to be used.

For example, in Jilin province a 40% increase of the daily rainfall in 62 operations during 1980-87 was shown by using the multi-target-control historical regression method, the significant level of which reached 0.01.

(2)❄The ground PE operations had fixed target area, historical regression method was usually used for evaluation the PE effect. For example PE operation in Fenghuang county (Hunan province) during 1975~77 showed an increase of 55% of the daily rainfall by statistics.

(3)❄A randomized PE experiment had been carried out in Gutian county, Fujian province in rainy season (Apr.-Jun.) during 1975-86, by using artillery and rockets. The target and control areas are 1500 km^2 each. Experiment unit was 3h. There were 244 experiment units half of which were seeded. Statistics showed an average rainfall increment of 23.8% with significant level of 0.05. Single station test showed that the center of the PE was located at 40 km down wind from seeding point.

(4)❄In orographic cloud seeding operation in Baiyang River (Xinjiang Region), the annual streamflow was used for evaluating the PE effect and the Halayimide River was chosen as the control. Statistics showed an increment of 11.6% of the streamflow during seed-ed 1984-95 in comparison with unseeded 1962-83; the significant level reached 0.025.

(5)❄Physical supports of cloud seeding effects were obtained by monitoring the evolution of cloud microstructure and radar echo etc. In some cases airborne observations show-ed a large increase of ice concentration, gradual broaden of the particle size distribution and significant decrease of LWC after seeding. Intensification of the radar echo in see-ded region was observed in many cases. Monitor of the concentration of Ag ion in precipitation in some experiments provided data for evaluating the seeding effect.

5. Future development of PE in China

5.1 Future demand

In future decades the water problem in the North of China will be sharpen with the rapid growth of population and national economy. Water scarcity will be an important factor, which restrict the development of our nation. PE will attract more attention from government and public as a tool of obtaining additional water from sky.

5.2. Foundation of development

At present PE technology is still in its developing stage. Many scientific-technical problems have not been completely resolved. However, we do have the scientific tools and techniques available to make necessary advancements. We have weather radar, airborne cloud physics instruments, satellites, effective cloud seeding agents and dispersal systems, laboratory facilities, operation-command systems, efficient statistical methods and realistic numerical cloud model of various scales etc.

5.3. Suggested objectives of future development

Two objectives of long-term development of PE in China are suggested as following:

(1)❄To strengthen the scientific research and experiments in order to make advance in the following key directions

*To develop and prove the PE concepts;

*To clarify the cloud condition suitable for PE and to develop the technology of its real-time detection;

*To optimize the cloud seeding method, and to develop the technology of its realization;

*To study the reliable method and technology for evaluating the PE effect.

(2)❄To improve the operation technology and facilities in order to rise the real efficiency of PE operation, based on the results of scientific research with consideration of the local characteristics

In order to resolve the key problems in science and technology of PE a proposal of the national PE research project for obtaining additional water supply is put forward. By taking advantages of different institutions and through national and international cooperation a long-term well designed PE experiment is suggested.

5.4. International cooperation

International cooperation is important for scientific-technological progress. Coope-ration between US-Thai and Russia-Syria in PE field has got good results. Introduction of advanced technology and equipment of monitoring, such as multi-functional radar of various wavelengths, airborne and ground-based microwave radiometers, technology of cloud parameter detection by using satellites, physical and chemical methods of tracking the seeding aerosols etc. will be very useful for China. Inter-comparison and improvement of seeding agents and numerical modeling, consultation of the experiment design and exchange of the information on both research and operation will be helpful for advance in PE.